A New Method for Measuring the Index of Refraction of a Gas for Different Light-Waves and the Results Obtained for Several Gases

BY

HARVEY CLAYTON RENTSCHLER

DISSERTATION

SUBMITTED TO THE BOARD OF UNIVERSITY STUDIES OF THE JOHNS HOPKINS UNIVERSITY IN CONFORMITY WITH THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

BALTIMORE

1908

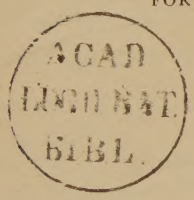
A New Method for Measuring the Index of Refraction of a Gas for Different Light-Waves and the Results Obtained for Several Gases

BY

HARVEY CLAYTON RENTSCHLER

DISSERTATION

SUBMITTED TO THE BOARD OF UNIVERSITY STUDIES OF THE JOHNS HOPKINS UNIVERSITY IN CONFORMITY WITH THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY



BALTIMORE

1908

OUTLINE

INTRODUCTION

1. Previous determinations of refractive indices of gases.
2. Relation between the density and the index of refraction of a gas.
3. Effect of temperature upon index of refraction.
4. Summary.

IMPORTANCE AND OBJECT OF THE PRESENT INVESTIGATION.

METHOD

APPARATUS

SOURCE OF LIGHT

PREPARATION OF THE GASES

OBSERVATIONS

RESULTS

CONCLUSIONS

THE
ASTROPHYSICAL JOURNAL
AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOLUME XXVIII DECEMBER 1908 NUMBER 5

A NEW METHOD FOR MEASURING THE INDEX OF REFRACTION OF A GAS FOR DIFFERENT LIGHT-WAVES AND RESULTS OBTAINED FOR SEVERAL GASES

By HARVEY CLAYTON RENTSCHLER

INTRODUCTION

1. *Previous determinations of refractive indices of gases.*—The problem of finding the index of refraction of a gas, and its relation to the density of the gas, is an old one and one which has been undertaken by a great many investigators. The earliest value for the index of refraction of air was deduced from astronomical observations, for white light, by Delambre.[1] Biot and Arago[2] used a hollow prism filled with air and observed, by means of a telescope, the apparent change of position of an object seen through the prism, when the pressure of the air in the prism was changed.

Ketteler[3] was the first to study the dispersion of gases. Between the plates of a Jamin interferometer he placed two tubes of equal lengths filled with the gas to be investigated. The pressure of the gas in one tube was changed and the fringe shift observed for a known change of pressure. In this way he determined the absolute value for the indices of refraction of yellow sodium light for air, carbon dioxide, hydrogen, sulphur dioxide, and cyanogen. By using a mixture of sodium and lithium in the flame, he observed the number of

[1] Laplace, *Mécanique céleste*, 4, 237, 246, 272, 1805.

[2] *Mém. de l'Inst.*, 7, 301–385, 1806.
Pogg. Ann., 124, 390, 1865.

red lithium fringes that passed the cross-hair of his telescope at the same time that a definite number of yellow sodium fringes passed, and so determined the relative value of the index of refraction for red lithium light and similarly for green thallium light.

Lorenz[1] repeated some of Ketteler's measurements with sodium and lithium light and determined the refractive indices for air, hydrogen, oxygen, and nitrogen. Mascart[2] measured the absolute values of the indices of refraction of air and chlorine for sodium light and the relative values for the four cadmium lines $\lambda = 6439$, 5378, 5086, and 4800. He divided a beam of light into two parts, which were passed through two parallel tubes filled with the gas, then recombined them and passed them through a spectroscope. If the pressure in the one tube be raised or that in the other lowered, Talbot bands appear in the spectrum, owing to the change in the optical path. By counting the number of bands that pass for a definite change in pressure he determined the index of refraction.

Chappuis and Rivière[3] used a Jamin interferometer to determine the index of refraction of air for sodium light. Walker,[4] using the same method, also determined the indices of refraction of air, hydrogen, carbon dioxide, and ammonia.

Kayser and Runge[5] placed a hollow prism between a large concave grating and the photographic plate and measured the displacements of various spectral lines when the pressure of the air in the prism was changed from zero to ten atmospheres. In this way they determined the indices of refraction of air for different wave-lengths from $\lambda = 5630$ to 2360.

Hasselberg[6] proposed to measure the displacements of the spectral lines when the pressure of the gas in the prism was changed from zero to one atmosphere and then turn the prism through 180° and again measure the displacements.

[1] *Wied. Ann.*, **11**, 70, 1880.

[2] *Comptes Rendus*, **86**, 321, 1878.

[3] *Ann. de Chim. et de Phys.* (6), **15**, 1888.

[4] *Phil. Trans.*, **201**, 435, 1903.

[5] *Annalen der Physik*, **50**, 293, 1893.

[6] *Ofversigt af Kongliga Veten-skaps. Akademiens Forhandlingar*, November 1892, p. 441.

And recently the refractive index of light in helium and argon has been determined by W. Burton[1] and for helium, gaseous mercury, sulphur, and phosphorus, within the limits of the visible spectrum, by C. Cuthbertson[1] and E. P. Metcalfe.

2. *Relation between density of a gas and the index of refraction.*—Ketteler[2] found that for equal changes of the pressure of a gas there was the same fringe shift and so concluded that $\frac{n-1}{d}=\text{constant}$, where n is the index of refraction and d the density.

Mascart[3] concluded, from an extensive research on the effect of pressure on the index of refraction of air, that up to 8 atmospheres pressure $\frac{n-1}{d}=\text{constant}$ to within limits of experimental error.

Chappuis and Rivière[4] found that, up to 20 atmospheres pressure, for air and carbon dioxide $n-1$ is strictly proportional to the density; while Gale,[5] using a slightly modified form of a Jamin interferometer and an improved device for measuring pressures, found that up to 20 atmospheres, if there is any departure from the law of Gladstone and Dale (namely, $\frac{n-1}{d}=\text{constant}$), this departure does not exceed one-tenth of 1 per cent. for air.

3. *Effect of temperature upon index of refraction.*—On varying the temperature of air, Mascart found that the index of refraction decreases more rapidly than the density with increasing temperature, but von Lang[6] obtained an opposite result.

Benoit[7] using a Fizeau expansion apparatus, by observing the shifts of Newton's rings for the same change of pressure of the gas between the plate and lens, when the gas was first at one temperature and then at another, found that for air the diminution of refraction was exactly proportional to the diminution of density, when the temperature was raised. Chappuis and Rivière (*loc. cit.*) obtained the same result for cyanogen and Walker[8] found the same for air, hydrogen, carbon dioxide, and ammonia.

1 *Nature*, **78**, 45, 1908.
2 *Pogg. Ann.*, **124**, 390, 1865.
3 *Comptes Rendus*, **86**, 321, 1878.
4 *Ann. de Chim. et de Phys.* (6), **15**, 1888.
5 *Phys. Rev.*, **14**, 1, 1902.
6 *Pogg. Ann.*, **153**, 448, 1874.
7 *Journal de Physique*, **8**, 451, 1889.
8 *Loc. cit.* (*Phil. Trans.*, **201**, 435, 1903.)

4. *Summary.*—From the above data the three following facts are brought out: (1) That air is the only gas for which the index of refraction has been determined experimentally for light of wave-length below $\lambda = 4800$; (2) That $(n-1)$ for a gas is directly proportional to the density of the gas; (3) That the change of refractive index of a gas is exactly proportional to the change of density, when the temperature of the gas is changed.

IMPORTANCE AND OBJECT OF THE PRESENT INVESTIGATION

The indices of refraction of many transparent solids and liquids have been measured over a wide range of wave-lengths not only in the visible but also in the infra-red and ultra-violet parts of the spectrum, and the various dispersion formulae tested. In order to test these same formulae for gases, it is necessary to know the values of the indices of refraction over a much larger range of wave-lengths than have been measured previously. The importance of these measurements, especially for the extreme ultra-violet, where many of the gases absorb light very strongly, was suggested to the writer by Professor R. W. Wood. Again Drude[1] has deduced, from purely optical properties of bodies, a value for $\frac{e}{m}$ which demands a very accurate knowledge of the dispersion.

In comparing different modes of solving the problem the following scheme occurred to me, by which the indices of refraction for different wave-lengths over the entire spectrum could be measured at the same time. The object of the present investigation was to develop this method, and to measure the indices of refraction of several gases as far out in the ultra-violet as possible with the apparatus available.

METHOD

If light consisting of different frequencies of vibration, from a slit wide open, is made parallel and then passed through a Fabry and Perot interferometer to a concave grating, the spectral images of the slit and the Fabry and Perot interference circles are brought to the same focus. In other words, the interference circles due to the different frequencies of vibration of the light are entirely separated, provided the spectral lines are not too close together. If, now, the slit is made

[1] *Annalen der Physik* (4), **14**, 677, 1904.

narrow and the interferometer so placed that the light passes through it normal to the plates, there will appear only sections through the center of the circles, of the same width as the slit-image. Owing to the multiple reflections between the plates these circles are very sharp, their diameters can be measured very accurately, and the order of interference at the center of the circles can be calculated to the hundredth, or, at most, the fiftieth part of a fringe. This consists, in general, of a whole number P and a fraction a. If the interferometer is put in a closed tube with windows at the ends and the gas slowly pumped out, the optical distance between the plates becomes smaller and the interference circles collapse toward the center, new ones appearing on the outside. In order to get the index of refraction of the gas, the number of circles that disappear at the center for a definite pressure change must be known. This number is obtained in the following manner. The fringes are photographed with the gas between the plates at atmospheric pressure. The pressure is then reduced to about one-seventh of an atmosphere and the fringes again photographed. Finally the tube is exhausted and the fringes photographed. The diameters of the circles are then measured and the values of a are calculated for every line in each case. Let the difference between a for atmospheric pressure and a for zero pressure be called a'. Therefore the gas between the plates under atmospheric pressure increases the optical path-difference between any two successive reflections from the same initial ray, emerging from the interferometer, over the path-difference between the same two reflections at zero pressure by some whole number $x'+a'$ wave-lengths. Similarly let a'' represent the difference between a for one-seventh of an atmosphere pressure and a for vacuum and x'' the whole number corresponding to this change of pressure. Accordingly one-seventh of an atmosphere change of pressure produces an increase in path-difference of $x''+a''$, while a change of pressure of one atmosphere produces an increase in path-difference of $x'+a'$ wave-lengths.

But it was shown in the introduction that $n-1$ is directly proportional to the density, or for small pressures where Boyle's law applies, directly proportional to the pressure, so that $x''+a''=\frac{1}{7}(x'+a')$. But x' and x'' are both unknown, so that x' is roughly determined for some line in the visible spectrum by counting the number of circles

that form at the center and spread out, while the gas is slowly entering the tube. By trying different numbers for x' in equation $x''+a''=\frac{1}{7}(x'+a')$, that number which gives the value of a'' found by experiment is determined.

Owing to the small dispersion of gases, the value of x' for a second spectral line separated from the first by not more than a few hundred Ångström units is approximately the same as for the first line except in the immediate neighborhood of an absorption band. (Here the lines must be closer together or extra readings at pressures between zero and atmospheric pressure must be taken in order to determine x' definitely. It is very desirable in the neighborhood of an absorption band to have the lines close together for another reason, namely, to get more points on the dispersion-curve where it changes most rapidly. The exact value of x' for this second line is found in the same way as for the first line and so on throughout the entire spectrum.

The following values observed for air will serve to make the above clear. For the line 5769 at 0.25 cm of mercury pressure a was 0.497; at 12.26 cm pressure a was 0.819, and at 74.95 cm pressure a was 0.815. That is, a change of pressure of 74.70 cm (0.25 cm to 74.95 cm) produced a change in the optical path of $(x'+0.318)$ wave-lengths; while a change of pressure (from 0.25 cm to 12.26 cm) of 12.01 cm produced a change of $(x''+0.322)$ wave-lengths. But the second pressure-change is $\frac{1}{6\cdot 22}$ that of the first and therefore $(x''+0.322)=\frac{1}{6\cdot 22}(x'+0.318)$. It was found by visual observation that x' for the line 5460 was 8 and so x' in the above equation cannot differ from 8 by more than two or three units. The following table gives the calculated values for a'' corresponding to all values of x' from 2 to 14. The value of a'' observed was 0.322. It is at once evident that the only value of x' in the neighborhood of 8, for which th observed and calculated values of a'' agree, is 8. While for $x''=14$ the observed and calculated values of a'' agree fairly well, this value is out of the question, as it would indicate the doubling of the index of refraction, from $\lambda=5460$ to λ 5769, in a region with no absorption band.

Again, for an extra reading at say $\frac{1}{13}$ of an atmosphere pressure, the observed and calculated value taking $x'=14$ would have disagreed. Such an extra reading was taken for every other gas than

air. This was deemed unnecessary for air, as all the preliminary work was done with air and so the approximate values were known to within one or two units.

$x'+0.318$	$x''+a''$ calculated from first column, using equation $(x''+a'')=\frac{1}{.6.22}(x'+a')$
2.318	0.37
3.318	0.53
4.318	0.69
5.318	0.85
6.318	1.01
7.318	1.17
8.318	1.33
9.318	1.49
10.318	1.66
11.318	1.82
12.318	1.98
13.318	2.14
14.318	2.30

APPARATUS

The apparatus used is outlined in Fig. 1. A fused quartz vacuum mercury arc lamp *a* (which will be described more in detail below) was placed in front of the slit *b*. The light from the slit was made parallel by the concave glass mirror *c* of about eight inches focal length. The concave side was nickel-plated by the cathode discharge in a vacuum, nickel being used because of its reflecting power in the ultra-violet. *m* is a brass tube six inches long and three inches in diameter. To one end of this tube is soldered the brass plate *n*. In the middle of this plate there is a hole one inch square, covered by a quartz window *d*, attached to the plate with sealing-wax. To the other end of the tube is soldered a brass collar *g*. *h* is a brass plate with a hole one inch square in the center, covered by a quartz window *d'*. This plate *h* is joined to the collar *g* by means of six screws so that the tube can be opened and closed easily. A washer of pure gum is put between *g* and *h* to make the joint air-tight. The side tube *o* leads to a closed mercury manometer on which the pressure readings are taken with a cathetometer. The vessel *m* is connected to a Geissler-Toepler air pump through the side tube *s*, while *t* leads to the drying tube (a tube about eight inches long filled whith phosphorus pentoxide) and thence to the gas tank. The stopcocks *x* and *y* serve to disconnect the apparatus from the pump and gas-tank

respectively. The grating k had a focal length of 29.15 cm, and a ruled space of 2.5 inches with 14,000 lines to the inch. Unfortunately the grating is badly scratched, so that all but a small part of it had to be covered with black paper. Furthermore it gives the ultra-violet lines so weakly that, with the light passing first through the interferometer and then to the grating, no trace of any lines below $\lambda = 2967$ could be obtained even after an exposure of one and a half hours. The plate-holder is represented in the figure at l. Seed's "Orthochromatic" films were the only kind found to give satisfactory results for the green and yellow mercury lines and were used exclusively.

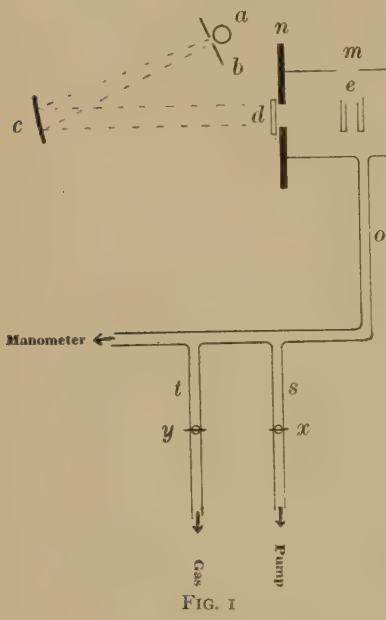


FIG. 1

The interferometer is shown in the diagram at e. The plates are plane-parallel quartz plates cut perpendicular to the optic axis. They were silvered chemically and the thin silver films polished with a little rouge on a powder-puff. This method was found by Dr. Pfund to work so remarkably well that the number of back-and-forth reflections between the plates is more than doubled.

The interferometer plates were made parallel by pressing them, by means of three springs, against the ends of a fused quartz ring, the ends of which were made very accurately parallel by A. Hilger of London, England. The pressure of any of these springs could be increased or diminished by means of a screw pressing the spring, and so the final adjustments for parallelism could easily be made by simply altering the pressure of one or another of the springs.

The object of using a fused quartz ring was to eliminate as much

as possible any slight temperature variations, fused quartz having an extremely low coefficient of expansion.

The support for the plates, etc., was so designed that it fitted neatly into the tube *m* so that it could be slid in and out easily without jarring it when it had to be taken out to make adjustments for parallelism of the plates. With the quartz ring between the plates they were found to keep their adjustment so well that often it was unnecessary to make any readjustments for several days.

The tube *m* was mounted so that it could be rotated slightly about both a vertical and a horizontal axis perpendicular to its length. This was necessary in order to orient the interferometer in such a way that the light went through it normal to the plates, so that the spectral images were sections through the center of the ring systems.

SOURCE OF LIGHT

The selection of a suitable source of light was by no means the easiest part of the investigation. The metallic arcs, like iron, which give very homogeneous radiations, were at once out of the question with the small dispersion of the grating used. Again, the metallic sparks, such as zinc and cadmium, which give lines nicely separated, are not homogeneous enough for interferometer work. A small mercury vacuum arc lamp similar to the Cooper-Hewitt lamp was used in all the preliminary work and found so satisfactory that the following form of quartz lamp was designed and used exclusively for the rest of the time (Fig. 2).

FIG. 2

A fused quartz tube *a* one foot long and $\frac{1}{4}$ inch in diameter had one end drawn out and an iron wire *c* sealed in with sealing-wax *f*. A glass tube *d*, fitting the quartz tube at *m*, was joined to the other end with sealing-wax. A small side tube *g* is used to exhaust it. The top of *d* is drawn out as indicated and an iron wire *e* is sealed in with sealing-wax. This wire is joined to an iron rod *k* about two inches long and about $\frac{1}{16}$ inch in diameter. Two small iron washers keep the rod from hanging to one side. There is about an inch and a half of mercury *b* in the bottom of the tube. The distance between the iron rod and the mercury is about

an inch. The lamp is exhausted with a mercury pump. The bottom of the lamp was always kept in water when used, but the top joints remained cool even when used a whole day long. It was joined in series with about 85 ohms to the terminals of the 110-volt D. C. circuit, the iron rod being made the anode. It was started by applying a small flame to the quartz tube and boiling the mercury till it formed contact with the iron rod and lit up. The lamp could be used a whole day long without requiring any attention whatever.

PREPARATION OF THE GASES

The gases used in the present investigation were air, oxygen, nitrogen, carbon monoxide, and carbon dioxide. The gases were collected in a large bottle by displacement of water. The gas was carefully dried by slowly passing it through a tube containing phosphorus pentoxide, as it passed to the vessel where it was used.

The oxygen was prepared by electrolysis of distilled water containing a few drops of pure sulphuric acid.

The nitrogen was prepared by gently heating a solution of ammonium chloride and sodium nitrite.

The carbon monoxide was prepared by heating oxalic acid and concentrated sulphuric acid. The gas thus obtained was slowly bubbled through three different concentrated solutions of potassium hydroxide in order to get rid of all the carbon dioxide formed with the monoxide. The carbon dioxide was prepared with a Gibbs apparatus, from marble and hydrochloric acid. The gas was passed through water to get rid of all traces of acid which might come over with the carbon dioxide.

OBSERVATIONS

Owing to the varying sensitiveness of the photographic film for different wave-lengths and the difference in the intensities of the lines, the time of exposure necessary to give the best results varied for the different lines. An exposure of one minute was sufficient for the three lines λ 4358, 4046, and 3650; while the green line λ 5460 required four minutes and the yellow lines and the ultra-violet line $\lambda = 3341$, twenty minutes. A small cardboard screen was therefore placed in

front of the photographic film so that only the yellow and the ultra-violet part of the spectrum from about 3500 down was exposed. After a sufficient exposure had been given to these lines the screen was removed and after one minute more a screen of potassium bichromate was placed in front of the slit. (This transmits only the green and yellow lines and so the green line was given its required length of exposure.)

In all the exposures with the different gases the slit was made just narrow enough to separate the two yellow mercury lines.

The approximate thickness of the ring between the plates being known, the orders of the first interference rings from the center were calculated from an exposure taken with air at atmospheric pressure for the green, the blue, and one of the yellow lines, and so the exact distance between the plates was found to be 9.0065 mm.

For each gas investigated, except air, for which an extra reading was taken, the following six exposures were made, viz.:

1. Vessel containing the interferometer exhausted.
2. Gas in vessel at a pressure of about $\frac{1}{13}$ atmosphere.
3. Gas in vessel under a pressure of about $\frac{1}{6}$ atmosphere.
4. Gas in vessel at atmospheric pressure.
5. Vessel exhausted.
6. Vessel refilled with gas.

The fringe shifts for the various lines due to the difference between the pressures of the gas for the first and fourth exposures were now determined as described in the first part of the paper (exposures two and three serving to get the whole number). Similarly for the difference in pressures for the fourth and fifth exposures and also for the fifth and sixth. From these the fringe shifts for one atmosphere change of pressure were calculated and the mean of the three values determined. But it was shown in the introduction that the index of refraction varies with temperature at exactly the same rate as the density varies with temperature. So that we have at once the fringe shift at 0° C. for a change of pressure of one atmosphere is $(1+\alpha t)$ times the mean value determined above (where t is the Centigrade temperature of the gas when the readings were taken, and α is the coefficient of expansion of the gas). From the values thus obtained for the fringe shift at 0° C. for a change of pressure of one atmosphere

for the distance between the plates given above, the indices of refraction were calculated for the various lines.

The following figures (Table I) are the values obtained for air and will serve to show how the results agree.

The order in which the exposures were taken is given in column one. Columns two to six give the values of a, calculated from the diameters of the circles for the different mercury lines whose wavelengths are given above the columns. In the last column are given the pressures of the gas at which the exposures were made. The seventh horizontal row gives the number of fringe shifts for the various pressure changes given at the end of this row. These fringe shifts for the various pressures were obtained from the table in the manner explained in the first part of the paper. In the eighth row are given the fringe shifts calculated for a change of pressure of one atmosphere.

The ninth row shows the average values of row eight, while the tenth row shows the values calculated for 0° C., and the last row gives the refractive indices calculated from the tenth row.

TABLE I

AIR. TEMPERATURE 21°.1 C.

	$\lambda=5769.6$	$\lambda=5460.7$	$\lambda=4358.3$	$\lambda=4046$	$\lambda=3650$	$\lambda=3341$	Pressure
1	.815	.622	.217	.324	.435	.837	74.95 cm *Hg*
2	.819	.198	.824	.162	.068	.270	12.26
3	.497	.812	.067	.250	.928	.930	12.25
4	.791	.596	.173	.279	.368	.830	74.67
5	.498	.824	.094	.288	.955	.962	74.37
6	.807	.605	.202	.314	.381	.841	74.70
From 1 and 3	8.318	8.810	11.150	12.074	13.507	14.907	74.70
3 and 4	8.294	8.784	11.106	12.029	13.440	14.900	74.42
4 and 5	8.293	8.772	11.079	11.991	13.413	14.868	74.30
5 and 6	8.309	8.781	11.108	12.026	13.426	14.879	74.33
For 76 cm. *Hg* pressure at 21°.1 C.	8.463	8.963	11.344	12.284	13.742	15.166	
	8.470	8.970	11.341	12.284	13.725	15.215	
	8.483	8.973	11.333	12.266	13.720	15.208	
	8.496	8.979	11.358	12.297	13.728	15.213	
Average	8.478	8.971	11.344	12.283	13.729	15.200	
For 0° C.	9.132	9.663	12.219	13.231	14.789	16.373	
Index of refraction	1.0002925	1.0002930	1.0002956	1.0002972	1.0002997	1.0003036	

The values for the fringe shifts given in row 8, Table I, seldom differ from the average value by more than 0.015 so that the probable error in row 9 should not exceed this amount. This corresponds to

an error of not more than four units in the seventh decimal place for the indices of refraction.

RESULTS

In Table II are given the indices of refraction of the different gases investigated for 0° C. and 76 cm *Hg* pressure. The curves of Fig. 3

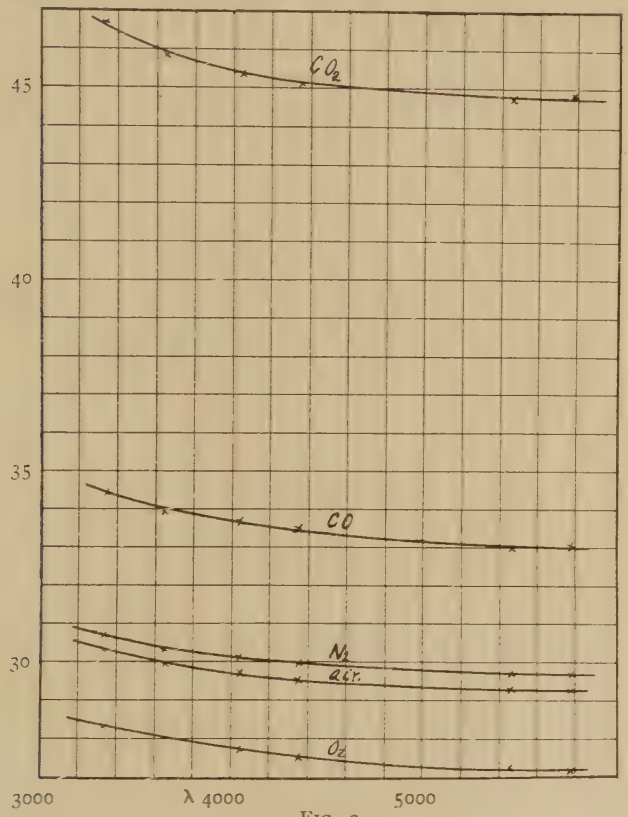


FIG. 3

are plotted with wave-lengths as abscissae and indices of refraction as ordinates.

TABLE II

Gas	λ=5769	5460	4358	4046	3650	3341
Air.....	1.0002925	1.0002930	1.0002956	1.0002972	1.0002997	1.0003036
Oxygen.....	1.0002719	1.0002725	1.0002752	1.0002776		1.0002832
Nitrogen.....	1.0002966	1.0002967	1.0002995	1.0003010	1.0003034	1.0003070
CO.....	1.0003303	1.0003299	1.0003346	1.0003366	1.0003396	1.0003442
CO_2.....	1.0004487	1.0004470	1.0004513	1.0004539	1.0004582	1.0004668

The dispersion formulae for the different gases were next calculated. The average value of the indices for the first two lines was taken as the true value for the index for the wave-length which is the mean of the two wave-lengths, and similarly for the next two lines and

TABLE III

AIR. FORMULA $(n-1)\ 10^7 = 2903.1 + 3.80\ \lambda^{-2} + 1.23\ \lambda^{-4}$

Wave-Length	$(n-1)\ 10^7$ Observed	$(n-1)\ 10^7$ Calculated
5769	2925	2925.6
5460	2930	2929.6
4358	2956	2957.2
4046	2972	2972.2
3650	2997	3000.8
3341	3036	3035.8

NITROGEN $(n-1)\ 10^7 = 2941 + 3.81\ \lambda^{-2} + 1.21\ \lambda^{-4}$

5769	2966	2963.4
5460	2967	2967.3
4358	2995	2994.6
4046	3010	3009.4
3650	3034	3037.7
3341	3070	3072.2

OXYGEN $(n-1)\ 10^7 = 2697.4 + 3.72\ \lambda^{-2} + 1.26\ \lambda^{-4}$

5769	2719	2719.9
5460	2725	2724
4358	2752	2751.9
4046	2776	2777.1
3650		2795.5
3341	2832	2831.8

CARBON MONOXIDE $(n-1)\ 10^7 = 3241.2 + 17.01\ \lambda^{-2} + .58\ \lambda^{-4}$

5769	3303	3298
5460	3299	3304
4358	3346	3346.7
4046	3366	3366.7
3650	3396	3401.6
3341	3442	3440.1

CARBON DIOXIDE $(n-1)\ 10^7 = 4490.4 - 16.55\ \lambda^{-2} + 4.03\ \lambda^{-4}$

5769	4487	4477
5460	4470	4480.3
4358	4513	4515.1
4046	4539	4539.6
3650	4582	4593.1
3341	4668	4665.5

the last two lines. These values were substituted in the three-constant Cauchy formula $n = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4}$ and the constants found. In Table III are given the formulae thus obtained; the calculated and observed values are tabulated side by side. In these formulae λ is expressed in thousanths of a mm.

For the sake of comparison the indices of refraction of the gases studied in the present work were calculated for yellow sodium light $\lambda = 5893$. In Table IV are given the values for the indices of refraction of these gases for sodium light as found by different investigators.

Investigators	Air	Nitrogen	Oxygen	Carbon Dioxide
Ketteler	1.0002947	.....	.....	1.000449
Lorenz	1.00029108	1.0002960	1.00027155	1.000449
Mascart	1 0002927	.....	.....	1.000454
Chappuis et Rivière	1.0002919	.....	.....	.....
Benoit	1.0002923	.....	.....	.....
Walker	1.00029288	.....	.....	1.0004510
Kayser and Runge	1.0002922	.....	.....	.....
Rentschler	1.0002924	1.00029619	1.0002718	1.0004475

CONCLUSIONS

With the method fully developed there will be no difficulty in extending the readings for the refractive indices of the different gases to the extreme end of the ultra violet, provided a good grating is used. As the reflecting power of silver is low in the region from about $\lambda = 2800$ to 3150 it would be better to use nickel films on the interferometer plates deposited by the cathode discharge in a vacuum. These nickel films have been used by Fabry and Perot in their work on standard wave-lengths and found very satisfactory. Owing to lack of time I have not yet been able to extend my readings below $\lambda = 3341$.

PHYSICAL LABORATORY
JOHNS HOPKINS UNIVERSITY

BIOGRAPHICAL NOTE

Harvey Clayton Rentschler was born on March 26, 1881, in Hamburg, Berks Co., Pa. His early education was received in the public schools of his home township, and at Perkiomen Seminary, Pennsburg, Pa. He entered Princeton University in the fall of 1899 and received the degree of A.B. in 1903. During the year 1903–4 he held the Experimental Science Fellowship at Princeton and received the degree of M.A. in 1904. In the year 1904–5 he was instructor in physics at Princeton. In the fall of 1905 he entered the Graduate Department of the Johns Hopkins University, taking physics as his principal subject, and physical chemistry and applied electricity as his subordinates. During the spring term of 1907 he had charge of the physics courses at Pennsylvania College, Gettysburg, Pa. During the years 1905–8 he has attended the lectures given by Professors Ames and Wood in physics, Professor Jones in physical chemistry, and by Dr. Whitehead in applied electricity.